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13. ABSTRACT *(Maximum 200 words)*

A new rough surface scattering theory which reduces to the composite surface scattering model is developed. It is based on the use of a normalized first order smoothing approximation in conjunction with the proper use of stationary phase to bring out the large scale surface shadowing. The theory provides the basis for improving on the conventional composite model.

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A NEW COMPOSITE ROUGHNESS SURFACE SCATTERING MODEL

Final Report

by

Gary S. Brown

20 January 1992

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STATEMENT OF THE PROBLEM

Scattering of electromagnetic fields by randomly rough, extended surfaces comprises an extremely difficult mathematical problem. In spite of this difficulty, basic understanding of the physics of the processes involved must be developed. This understanding is essential to the development of models for the prediction of the effects of rough surfaces on electromagnetic waves. The applications of such models are almost unbounded because rough surfaces are significantly more numerous, in nature, than smooth surfaces.

The mathematical difficulty of this problem has been a major hinderence in its solution. Recently, direct numerical solutions of the basic integral equations governing the scattering processes have been accomplished. However, these have been limited to one-dimensional or corduroy surfaces and, even so, have been limited in their ability to study and parameterize naturally occuring scattering situations. The reason for this limitation is that the problem is still too large for even the fastest and largest (in memory capacity) computers. Furthermore, the numerical solution of the basic equations is generating a whole new set of difficulties which will take time and effort to solve. Consequently, there is still a great need for an analytical based solution for the full two-dimensional surface roughness problem.

One of the most successful scattering models to be developed for natural (terrain and ocean) surfaces is the so called composite roughness surface scattering model. In this model, the surface roughness spectrum is split into parts. The low (spatial) frequency part comprises spectral components whose wavelengths are large compared to the incident electromagnetic wavelength while the remaining part of the roughness spectrum encompasses the wavelengths which are comparable to or shorter than the electromagnetic wavelength. The key to the composite surface method is to use a low frequency approximate technique to analyze the scattering from the small wavelength features on the surface, a high frequency method for the long wavelength surface features, and some technique which properly estimates the degree to which these two scales of roughness mutually affect the scattering process. There is such a model available; it uses physical optics to predict the scattering from the low frequency part of the roughness spectrum and perturbation theory to estimate the scattering from the high frequency part. The interaction comes about through the tilting of the perturbation scattering solution by the low freqquency surface spectral components. This interaction provides for the smooth transition between the perturbation and physical optics solutions.

The major advantage to this scattering model is that it shows how two asymptotic solutions can be combined to predict the scattering from a class of multi-scale surfaces. The disadvantage or drawback to the model is that it is not readily extended to surfaces which do not obey the assumptions of the model and it is not clearly obvious when the model starts to break down. The purpose of this research is to develop a new analytical scattering theory which is capable of reducing to the composite surface scattering model and can be extended to surfaces which do not obey the assumptions of the classical composite surface scattering model.

SUMMARY OF MOST SIGNIFICANT RESULTS

The most significant result of this research is that we have been able to accomplish almost exactly what we set out to do. That is, we have developed an improved analytical scattering model that contains all of the physically intuitive features of the conventional composite surface scattering model and clearly shows how to systematically improve on it. This new theory has a number of crucial parts which are outlined below. A paper detailing the derivation of the theory is presently in preparation and will be submitted to a major journal.

The basic approach starts with the magnetic field integral equation for the current induced on a perfectly conducting rough surface by an incident field. The height dependent phase term in the source or Kirchhoff term of this equation is normalized out of the equation so that the method of smoothing can be applied to obtain an approximate solution of this equation. Without the normalization, first order smoothing (FOS) will fail as the surface height increases in magnitude relative to the electromagnetic wavelength. This failure of FOS will take place irrespective of the horizontal variability of the roughness and will, in fact, occur even if we have a randomly elevated planar surface. It is a consequence of the perturbative (in height) nature of the FOS approximation. The advantage and strength of the FOS approximation is that it provides a solution that does not require small surface height derivatives and this is a considerable advantage over conventional perturbative approximations.

The next part of the analysis comprises splitting the surface roughness height into the sum of a small scale component relative to the em wavelength and a large scale component. The small scale component is assumed to cover all surface features which have a wavelength that is comparable to or smaller than the em wavelength. The large scale component height covers all long wavelength (relative to the em wavelength) surface features. The intent of this spectral dichotomy is to use a theory which is appropriate to each spectral region since it is highly doubtful that any one approximate scattering theory will be adequate for the entire range of surface features.

We then split the infinite range integral in the integral equation into the sum of a finite range integral centered on the point of observation of the current and an infinite range integral covering the entire remainder of the z=0 plane. The extent of the finite range integral is such that it contains at least four wavelengths of the longest wavelength component in the small scale height. Thus, for example, if we split the spectrum at three times the em wavelength, the finite range integral would cover twelve em wavelengths. The criterion of taking the integration range to be four times the longest wavelength in the small scale height is based on insuring that the finite range integral contains sufficient small scale surface variation as to be representative of the small scale. It may be possible to make this range somewhat less than the above criterion.

The sum of the normalized Kirchhoff term and the finite range integral term are now used as the new source or Born term. Since the large scale surface has been constructed such that it is very smoothly undulating, we can solve for its effect on the scattering process by iterating the integral equation (and its new Born term) and completing each integration via the method of stationary phase. It is very important to realize that stationary phase can be applied only after we have extracted the finite range integration from the integral we are to approximate via stationary phase. The reason for this is that we cannot apply stationary phase in a neighborhood of the point of observation (also the point of singularity in the normal derivative of the free space Green's function evaluated on the surface) because of the presence of the small scale surface structure. That is, stationary phase assumes that there is no structure on the surface that is smaller than or comparable to the em wavelength. Violation of this assumption makes no difference when the integration is well away from the point of obersvation; however, it is very important to satisfy this assumption when near to the point of singularity/observation.

Use of stationary phase leads to the introduction of a large scale dependent shadowing function which multiplies the normalized Kirchhoff term and the finite range integral term. However, the part of the equation that comprises the sum of these last two terms has as its solution the first order smoothing approximation or, more precisely, the normalized first order smoothing solution (NFOS) since it is the normalized equation that we are dealing with. Thus, our approximate solution of the normalized magnetic field integral equation is a large scale shadowed (normalized first smoothing) approximation for the small scale structure.

Reintroduction of the large scale dependent phase factor leads to a tilting effect of the underlying large scale surface. In short, our theory contains all of the conventional composite surface scattering model features. However, it also shows how one goes about going beyond the limitations of this model. For example, if there are large scale curvature effects that must be accounted for, our theory shows how they come into play in both the large scale solution and the small scale scattering. Hence, our theory, while still requiring a good deal more numerical work, satisfies nearly all of the goals of our original research proposal.

LIST OF ALL PUBLICATIONS AND TECHNICAL REPORTS

Gary S. Brown, "A new approach to the analysis of rough surface scattering," IEEE Transactiors on Antennas & Propagation, Vol 39, No. 7, pp. 943-948, July, 1991.

Gary S. Brown, "Clutter modeling for the real enviornment: what are the problems?," Proceedings of the International Meeting on Detection, Discrimination, and Classification of Targets in Clutter, USA Missile Command, Huntsville, AL, in press.

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None

BIBLIOGRAPHY:

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